NASA
Technical
Memorandum

NASA TM-82564

EVIDENCE LINKING CORONAL MASS EJECTIONS WITH INTERPLANETARY "MAGNETIC CLOUDS"

By Robert M. Wilson and Ernest Hildner
Space Science Laboratory

December 1983

(NASA-TM-82564) EVIDENCE LINKING CORONAL MASS EJECTIONS WITH INTERPLANETARY MAGNETIC CLOUDS (NASA) 25 p HC A02/MF A01 CSCL 03B

N84-18141

Unclas
G3/92 18452

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM -82564	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Evidence Linking Coronal Mass Ejections with Interplanetary "Magnetic Clouds"		5. REPORT DATE December 1983
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robert M. Wilson and Ernest Hildner		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration, Washington, D.C. 20546		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Space Science Laboratory, Science and Engineering Directorate.

16. ABSTRACT

Using proxy data for the occurrence of those mass ejections from the solar corona which are directed earthward, we investigate the association between the post-1970 interplanetary magnetic clouds of Klein and Burlaga and coronal mass ejections. The evidence linking magnetic clouds following shocks with coronal mass ejections is striking; six of nine clouds observed at Earth were preceded an appropriate time earlier by meter-wave type II radio bursts indicative of coronal shock waves and coronal mass ejections occurring near central meridian. During the selected periods when no clouds were detected near Earth, the only type II bursts reported were associated with solar activity near the limbs. Where the proxy solar data to be sought are not so clearly suggested, that is, for clouds preceding interaction regions and clouds within cold magnetic enhancements, the evidence linking the clouds and coronal mass ejections is not as clear; proxy data usually suggest many candidate mass-ejection events for each cloud. Overall, the data are consistent with and support the hypothesis suggested by Klein and Burlaga that magnetic clouds observed with spacecraft at 1 AU are manifestations of solar coronal mass ejection transients. A condensed version of this study is to be published in Solar Physics.

17. KEY WORDS Magnetic Clouds, Solar Wind, Coronal Mass Ejection, Sun	18. DISTRIBUTION STATEMENT Unclassified – Unlimited. Robert M. Wilson

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	24	NTIS

MSFC - Form 3292 (May 1969)

For sale by National Technical Information Service, Springfield, Virginia 22161

ACKNOWLEDGMENTS

The authors are grateful to L. Klein (Computer Sciences Corporation, Silver Spring, MD) and L. Burlaga (NASA/GSFC) for providing a preprint of their magnetic-cloud statistics paper and for helpful discussions. Also, we are grateful to R. Moore for critically reviewing early drafts of this paper, to E. Tandberg-Hanssen (NASA/MSFC) for helpful discussions, and to Jesse B. Smith, Jr. (NOAA) for providing the SGD's.

TABLE OF CONTENTS

LIST OF TABLES

TECHNICAL MEMORANDUM

EVIDENCE LINKING CORONAL MASS EJECTIONS WITH INTERPLANETARY "MAGNETIC CLOUDS"

INTRODUCTION

Recently, Burlaga et al. [1] investigated the configuration of the interplanetary magnetic field in a flow behind a shock using Voyager, Helios, and IMP 8 observations. For that single event, they found the configuration to be suggestive of an ordered "magnetic cloud," approximately 0.5 AU in radial extent and >30 deg in azimuthal extent. Further, each spacecraft, as it transited the magnetic cloud, observed that the magnetic-field direction in the cloud changed by rotating nearly parallel to a plane. In a subsequent paper, Klein and Burlaga [2] (hereafter referred to as KB) extended their study of their interplanetary phenomenon, discussing statistically the characteristics of 45 magnetic clouds observed near Earth by a number of individual spacecraft over a solar cycle (1967-1978). They noted that magnetic clouds pass Earth at the rate of at least one every 3 months and that they possess several common characteristics related to their structure and dynamics. Though the clouds present common characteristics and were thought to represent one phenomenon, they were found in three environments at 1 AU. Therefore, KB sub-divided the 45 magnetic clouds into three groups: (a) those following shocks (13 examples); (b) those preceding interaction regions (16 examples); and (c) those associated with CME's (i.e., Cold Magnetic Enhancements; 16 examples). Because of the quantitative similarities between their physical parameters (e.g., mass, speed, occurrence rate as corrected for data gaps, and internal magnetic-field strength) and those extrapolated for coronal mass ejections, KB suggested that magnetic clouds may be 1-AU manifestations of coronal mass ejections (also see Burlaga and Behannon [3] and Burlaga et al. [4,5]).

In an effort to evaluate this hypothesis, a study was undertaken of the 35 post-1970 KB events to ascertain if a one-to-one correlation existed between a magnetic-cloud observation and the occurrence of a candidate solar event thought to be diagnostic of a coronal mass ejection and occurring at the appropriate earlier time. For the clouds following interplanetary shocks, where the obvious proxy solar activity is a meter-wave type II burst [6], results are consistent with such a one-to-one correlation. The results allow such a correlation for the other two classes of clouds but do not require it; the appropriate observable solar events, which should be considered to be proxy for the observation of a coronal mass ejection, are not obvious in these latter two classes.

METHOD

Figure 1 shows a schematic solar cycle for the period of interest and the approximate occurrence dates of the magnetic clouds. In the figure, "X" denotes the occurrence of a pre-1970 cloud not studied in this investigation; "R_Z" is the smoothed Zurich sunspot number. This study relates particularly to the events which occurred at the time of the dots: (a) 9 clouds following shocks, (b) 13 clouds preceding interaction regions, and (c) 13 clouds associated with CME's. The division into subgroups (a), (b), and (c) is made solely on the basis of the environment in which the clouds are found at 1 AU; it is argued in KB that the satellite data do not suggest that there are systematic or causal differences between the clouds of separate subgroups. Therefore, in KB it is suggested that the three types of clouds might be manifestations of a single phenomenon.

ORIGINAL PAGE IS OF POOR QUALITY

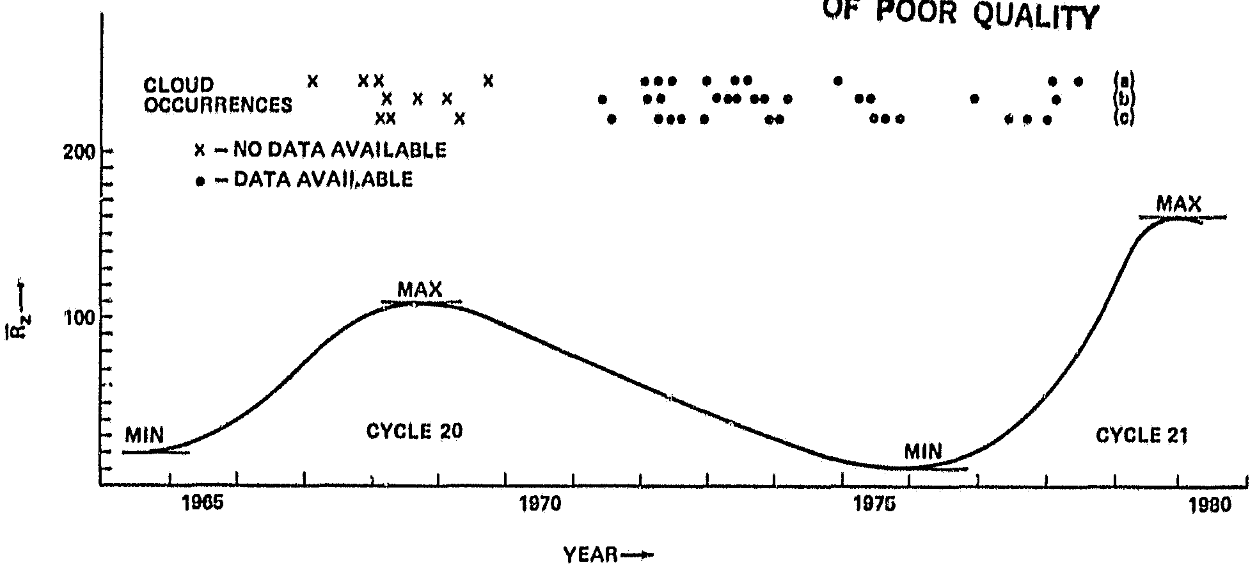

Figure 1. Magnetic cloud occurrence versus solar cycle (1964-1980). Cycle 20 and the rise-portion of cycle 21 are plotted schematically. Magnetic clouds are indicated by X and ● in a 3-tier scheme corresponding to the subgroups of magnetic clouds identified by Klein and Burlaga (1982). The subgroups are: (a) following shocks; (b) preceding interaction regions; and (c) associated with CME's.

Table 1, adapted from KB, identifies the number, average duration, average solar wind speed, and average travel time by subgroup and for all 45 magnetic clouds. The clouds are found to have an average duration of 25.6 hr, and the average solar wind speed during cloud passages is 416 km s^{-1}. These numbers imply that the average radial extent of magnetic clouds is about 0.25 AU. Average travel time, Sun to 1 AU, is simply 1 AU (= 1.5×10^8 km) divided by the average speed. Thus, clouds average about 4.3 days transit time. Solar wind speeds were obtained from tabulations compiled by King [7-9].

TABLE 1. INTERPLANETARY CLOUD SUMMARY DATA

SUBGROUP	NO. EVENTS	MEAN DURATION[1]	AVERAGE SPEED[2]	AVERAGE TRAVEL TIME[3]
MAGNETIC CLOUD FOLLOWING SHOCK (a)	13	26.2	463.9	92.4
MAGNETIC CLOUD PRECEDING AN INTERACTION REGION (b)	16	20.8	411.1	105.0
MAGNETIC CLOUD ASSOCIATED WITH A CME (c)	16	30.0	382.4	109.9
ALL MAGNETIC CLOUDS	45	25.6	416.2	103.1

[1]MEAN DURATION IN HR.

[2]AVERAGE SPEED IN km s^{-1}

[3]AVERAGE TRAVEL TIME IN HR.

KB's suggestion that magnetic clouds and coronal mass ejections are closely linked appears to be well-founded, since some of the physical properties of clouds and mass ejections (especially average speed and mass) are quantitatively quite similar. The magnetic cloud average speed is about 420 km s^{-1}, and estimated average mass is about 2 x 10^{15}g; coronal transient average speed is about 470 km s^{-1} and average excess mass is in the range 4 x 10^{15}g [10] to 8 x 10^{15}g [11]. Also, in KB it was noted that coronal mass ejections are always observed to leave the vicinity of the Sun (apparently never to return) and to expand as they move outward; magnetic clouds similarly move outward and likewise appear to be expanding (even at 1 AU and beyond [3]).

Coronal mass ejections have been associated by many investigators with such solar phenomena as flares, ascending or eruptive prominences, disparitions brusque, sprays, surges, type II and/or IV and gradual-rise-and-fall (GRF) radio events, long-decay X-ray events (LDE), prompt interplanetary protons, and white-light coronal transients (e.g., [12-40]). Indeed, many of these phenomena appear to be closely interrelated; for example, white-light coronal transients have been associated with eruptive prominences and flares, LDE's and GRF's with eruptive prominences (or disparitions brusque/disappearing filaments when seen against the solar disk), and type II and IV radio events with flares and eruptive prominences. Thus, the modus operandi for investigating the premise that magnetic clouds are the 1-AU manifestation of coronal mass ejections was to search records within appropriate time windows for the occurrence of these phenomena, regarding them as indicative or diagnostic of the occurrence of coronal mass ejections. The occurrence data regarding solar phenomena was extracted from the Prompt Reports and Comprehensive Reports of Solar Geophysical Data (SGD).

Using the occurrence of clouds as defined and tabulated in KB and solar wind speed data from King's [7-9] compilations for these events (in particular, the minimum observed solar wind speed, V_{MIN}, and the maximum, V_{MAX}), a temporal window for each cloud was computed within which a diagnostic event would have had to occur at the Sun to signal the initiation of an ejection event capable of reaching the spacecraft observing the cloud. These periods are called "cloud" or "event" windows. For example, in Table II, event 5 is a magnetic cloud that commenced on January 21 at 0300 UT (JAN 21.125) and had a duration of about 21 hr. During this interval, King's data reveal V_{MIN} and V_{MAX} to be 416 and 472 km s^{-1}, respectively. Thus, the event-window begin date/time is simply the cloud occurrence date/time corrected for the travel time, presuming a constant V_{MIN} over the 1-AU distance. That is, 21.125 -1 AU/V_{MIN} = 16.952, or JAN 16 ~ 2300 UT. Similarly, the solar event-window end date/time for this cloud is 21.125-1 AU/V_{MAX} = 17.447, or JAN 17 ~ 1100 UT. Then, using the SGD, reports were listed of phenomena thought to be diagnostic of mass ejection events occurring within the windows. Because it is believed that the association between proxy solar events and coronal mass ejections is poor, a "grab-bag" approach was adopted and a list was made of all those phenomena which could easily be tabulated using SGD. These were: locations, sizes, and rise and fall times of flares (especially flares annotated with the letter codes H, L, R, U, and V meaning 'flare accompanied by a high-speed dark filament,' 'existing filament shows signs of sudden activation,' 'marked asymmetry in H-alpha line suggests ejection of high-velocity material,' 'two bright branches, parallel or converging,' and 'occurrence of explosive phase,' respectively); type II and IV radio events; radio gradual-rise-and-fall (GRF) events; and soft X-ray events. To conclude, the reported phenomena that arose from a single event were grouped. For example, along with the observance of a flare might go reports of type II and/or IV emission and a GRF, all arising about the same time, presumably from nearly the same solar location. It is assumed that such an event, with a multiplicity of reported diagnostic phenomena, is more likely to indicate the presence of an accompanying coronal mass ejection than is a solar event for which only a single diagnostic phenomenon is reported.

TABLE 2. MAGNETIC CLOUDS FOLLOWING SHOCKS SUMMARY DATA (SUBGRCUP A)

(a) EVENT NO.	DATE OF CLOUD OCCURRENCE	(b) CLOUD PASSAGE BEGIN TIME	(c) CLOUD PASSAGE DURATION	(d) V_{MIN}	(d) V_{MAX}	(d) V_{AVG}	(e) TT	EVENT WINDOW BEGIN	EVENT WINDOW END	(f) WINDOW DURATION	(g) Hα	(g) RADIO
5	01-21-72	0300	21	416	472	444	93.8	01–16 (2300)	01–17 (1100)	12	0	18
6	02-02-72	0500	38	380	414	397	105.0	01–28 (1600)	01–29 (0100)	9	0	0
7	03-22-72	0300	15	325	353	339	122.9	03–16 (1900)	03–17 (0500)	10	0	0
8	11-01-72	0200	22	389	662	526	79.2	10–27 (2200)	10–29 (1500)	41	156	299
9	04-13-73	0000	48	342	575	459	90.8	04–08 (0600)	04–10 (0400)	46	89	9
10	05-21-73	0400	17	589	754	672	62.0	05–18 (0600)	05–18 (2200)	16	0	115
11	10-12-74	1200	10	398	518	458	91.0	10–08 (0500)	10–09 (0500)	24	3	0
12	01-04-78	1000	34	464	673	569	73.2	12–31 (1900)	01–01 (2200)	27	268	0
13	04-03-78	1800	21	430	515	473	88.1	03–30 (1800)	03–31 (1000)	16	236	0

[a]NUMBERING IS AS IN KB

[b]TIME IN UNIVERSAL TIME (UT)

[c]TIME IN HOURS

[d]VELOCITY IN km s^{-1}

[e]TRAVEL TIME (TT) IN HOURS

[f]WINDOW DURATION IN HOURS

[g]OBSERVING OUTAGES WITHIN THE WINDOW TOTAL THE NUMBER OF MINUTES LISTED

ORIGINAL PAGE IS OF POOR QUALITY

To determine that any associations that might be found between interplanetary clouds and solar phenomena were not merely accidental coincidences, control periods when no magnetic clouds were emitted earthward were examined and the same "diagnostic" solar activity phenomena as for the cloud windows were listed. Using these data, the frequency, types, and locations of solar activity which occurred when magnetic clouds were not emitted earthward were compared with the frequency, types, and locations of activity which occurred around the time when clouds were emitted.

A control period, called a "pre-cloud" window, was selected for each reported cloud as follows. To be sure that no cloud was emitted earthward during the control period, it was required that good solar wind data exist at a later time, allowing for transit of a hypothetical cloud to 1 AU, but that no cloud was reported in KB. For a target period of 24-hr duration, ending 72 hr before the event window began, the existence of 1 AU solar wind data at the appropriate (transit) time later was verified. These data were required to be good enough (i.e., no gaps in the solar wind coverage) to detect the passage of a magnetic cloud had it occurred. The appropriate transit time was taken to be the average transit time of the class of clouds being considered; that is, for pre-cloud windows paired with subgroup (a) cloud windows, the average transit time of the subgroup (a) clouds were used, and similarly for subgroup (b) and (c) pre-cloud windows. If the subsequent solar wind data were adequate, then the target period became the pre-cloud window; gaps in the associated solar wind data caused a shift from the target period sufficiently earlier or, rarely, later in time to ensure good solar wind data at 1 AU, a transit time later. The shifted 24-hr period became the pre-cloud window in these cases. This procedure ensured that no cloud was emitted earthward during a pre-cloud window. The pre-cloud windows were chosen to be 24-hr in duration for convenience; the average durations of the cloud windows were 22, 22, and 18 hr for subgroups (a), (b), and (c), respectively. Once the pre-cloud windows were identified, solar activity phenomena were catalogued exactly as already described for the cloud windows.

The results of these data compilations and the implications which flow from them are presented and discussed in the next section.

RESULTS AND DISCUSSION

The outcome of the search for proxy solar phenomena which would indicate the existence of coronal mass ejections is shown in the remaining tables of this report. Tables 2, 4, and 6 summarize information regarding the post-1970 magnetic clouds for each of the three subgroups, while Tables 3, 5, and 7 summarize information pertinent to the phenomena which might serve as proxies for mass-ejection events. The A portions of the odd-numbered tables are for the windows during which the magnetic clouds were emitted from the Sun, while the B portions refer to the pre-cloud windows. Note the number of: flares (as reported in the SGD Comprehensive Report); annotated flares (recall the H, L, R, U, and V descriptions); GRF's; X-ray events (as suggested by the tables of outstanding occurrences and/or plots that are contained in the SGD); and type II and/or IV spectral radio events. Further, note the number of events for which two or more diagnostic phenomena were observed and those for which three or more were observed.

The notes below the A portion of the odd-numbered tables refer to candidate solar events which might possibly be associated with the listed interplanetary magnetic clouds. The notes identify the H-alpha importance, solar coordinates, date and start time (UT) of each flare; the H, L, R, U, and V annotations, if any; the duration in minutes of any GRF's; the X-ray class; and the occurrence of type II and/or IV radio events. The candidate solar events listed in the notes to the tables are those with three or more reported diagnostic phenomena for magnetic clouds following shocks (Table 3A, except for clouds 7, 11, and 13) and those with two or more reported diagnostic phenomena for magnetic

TABLE 3A. SOLAR ACTIVITY SUMMARY DATA DURING CLOUD WINDOW PERIODS (SUBGROUP A)

EVENT NO.	NO. FLARES IN WINDOW	NO. ANNOTATED FLARES	NO. GRF's IN WINDOW	NO. X–RAY EVENTS IN WINDOW	NO. TYPE II's IN WINDOW	NO. TYPE IV's IN WINDOW	POSSIBLE NO. ASSOCIATIONS ≥2/≥3	NOTES
5	8	1	2	3	1	0	5/1	(1)
6	11	2	2	3	1	0	4/2	(2)
7	3	1	0	1	0	0	1/0	(3)
8	41	6	23	7	1	0	18/6	(4)
9	57	6	19	13	0	1	12/3	(5)
10	11	0	4	2	1	0	4/2	(6)
11	32	1	6	**	1	1	6/1	(7)
12	14	2	8	10	1	0	5/2	(8)
13	5	1	1	2	0	0	2/1	(9)

NOTES: **NO X–RAY DATA AVAILABLE

1. SF/S15E49 16/2255, C1, II
2. SF/S10W60 (H) 28/1739, GRF (70), C1
   1B/S10E26 (U) 29/0016, C1, II
3. SN/N10E59 (H) 16/2251, C0.7
4. 1B/S16E22 (L) 28/0422, GRF (19.5), M1
   {SN/S15E18 28/0923, SF/S14E18 (L) 28/0943} GRF (117), C9 (MP)*
   SN/S06W88 28/1239, GRF (>151), C5
   SN/S07E14 28/1531, GRF (7), C5
   SN/S10E10 (H) 28/1805, C4, II
   SB/S10E00 29/0928, GRF (23.4), C7
5. SN/S08E34 (U) 08/1415, GRF (79.5), C3, C4
   SN/S08W04 08/1733, GRF (83.1), IV
   SN/S08E20 09/1743E, GRF (220), M2
6. 1B/N07E43 18/1527, GRF (165), M2, II
   SB/N10E33 18/2154, GRF (30), M7
7. SN/N11E42 08/1311, GRF (10), IV
   SF/N07E47 08/1550, II
8. 1N/S22E16 31/2328, GRF (129), M1
   2N/S21E06 (UV) 01/2145, C2, II
9. SB/S26W27 30/2048, GRF (30), C1
   SN/S29W28 (H) 30/2332, C2

*MP: MULTIPLE PEAK

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 3B. SOLAR ACTIVITY SUMMARY DATA DURING SELECTED CONTROL PERIODS (SUBGROUP A)

PRE–EVENT WINDOW NO.	YEAR	BEGIN	END	NO. FLARES IN WINDOW	NO. ANNOTATED FLARES	NO. GRF'S IN WINDOW	NO. X–RAY EVENTS IN WINDOW	NO. TYPE II's IN WINDOW	NO. TYPE IV's IN WINDOW	POSSIBLE NO. ASSOCIATIONS ≥2/≥3
5	1972	01–12 (0500)	01–13 (0500)	4	0	1	0	0	0	0/0
6	1972	01–25 (0300)	01–26 (0300)	32	3	4	4	0	0	4/2
7	1972	03–12 (1900)	03–13 (1900)	4	0	1	0	0	0	0/0
8	1972	10–24 (1000)	10–25 (1000)	46	6	22	13	0	0	13/8
9	1973	04–04 (0600)	04–05 (0600)	15	4	7	1	2*	0	3/1
10	1973	05–14 (2300)	05–15 (2300)	10	1	4	8	0	0	0/0
11	1974	10–01 (2000)	10–02 (2000)	19	2	0	NXRA[1]	1	0	0/0
12	1977	12–27 (1900)	12–28 (1900)	10	4	5	8	3**	0	4/1
13	1978	03–26 (1900)	03–27 (1900)	7	1	1	0	0	0	0/0

* PROBABLY ONLY 1 EVENT (1154, 1203 UT START TIMES)

** 3 SEPARATE EVENTS ? (0354, 0735, 0800 UT)

1. NXRA MEANS NO X–RAY AVAILABLE

TABLE 4. MAGNETIC CLOUDS PRECEDING INTERACTION REGIONS SUMMARY DATA (SUBGROUP B)

(a) EVENT NO.	DATE OF CLOUD OCCURRENCE	(b) CLOUD PASSAGE BEGIN TIME	(c) CLOUD PASSAGE DURATION	(d) V_{MIN}	(d) V_{MAX}	(d) V_{AVG}	(e) TT	EVENT WINDOW BEGIN	EVENT WINDOW END	(f) WINDOW DURATION	(g) Hα	(g) RADIO
4	04-08-71	1000	17	331	374	353	118.0	04–03 (0500)	04–03 (1900)	14	0	4
5	01-15-72	1200	13	335	373	354	117.7	01–10 (0800)	01–10 (2100)	13	0	7
6	02-10-72	0300	18	352	401	377	110.5	02–05 (0500)	02–05 (1900)	14	0	0
7	01-20-73	1100	24	291	509	400	104.2	01–14 ([illegible]00)	01–17 (0800)	57	91	65
8	03-05-73	0300	24	314	382	348	119.7	02–27 ([illegible])	02–28 (1400)	23	73	3
9	03-31-73	2100	27	434	461	448	93.0	03–27 (2100)	03–28 (0300)	6	0	0
10	06-28-73	2000	16	430	635	533	78.2	06–24 (1900)	06–26 (0100)	30	72	0
11	07-26-73	0000	27	401	654	528	78.9	07–21 (2200)	07–23 (1200)	38	9	225
12	01-24-74	0000	30	297	361	329	126.6	01–18 (0500)	01–19 (0600)	25	156	34
13	03-27-75	0700	15	560	703	632	65.9	03–24 (0600)	03–24 (2100)	15	0	0
14	04-20-75	1100	20	388	513	451	92.4	04–16 (0200)	04–17 (0400)	26	0	0
15	12-07-76	0600	18	388	417	403	103.4	12–02 (1900)	12–03 (0200)	7	35	0
16	02-21-78	1200	21	335	368	352	118.4	02–16 (0800)	02–16 (1900)	11	545	0

[a] NUMBERING IS AS IN KB

[b] TIME IN UNIVERSAL TIME (UT)

[c] TIME IN HOURS

[d] VELOCITY IN $km\ s^{-1}$

[e] TRAVEL TIME (TT) IN HOURS

[f] WINDOW DURATION IN HOURS

[g] OBSERVING OUTAGES WITHIN THE WINDOW TOTAL THE NUMBER OF MINUTES LISTED

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 5A. SOLAR ACTIVITY SUMMARY DATA DURING CLOUD WINDOWS (SUBGROUP B)

EVENT NO.	NO. FLARES IN WINDOW	NO. ANNOTATED FLARES	NO. GRF's IN WINDOW	NO. X–RAY EVENTS IN WINDOW	NO. TYPE II's IN WINDOW	NO. TYPE IV's IN WINDOW	POSSIBLE NO. ASSOCIATIONS ≥2/≥3	NOTES
4	15	2	4	1	0	0	3/0	(1)
5	2	0	0	0	0	0	0/0	(2)
6	4	0	0	2	0	0	0/0	(3)
7	9	1	1	0	0	0	0/0	(4)
8	7	2	4	2	0	1	2/1	(5)
9	6	1	2	3	0	1	3/1	(6)
10	4	1	3	4	0	0	4/1	(7)
11	5	0	0	0	0	0	0/0	(8)
12	4	0	1	1	0	0	1/1	(9)
13	0	0	1	0	0	0	0/0	(10)
14	0	0	2	0	0	0	0/0	(11)
15	0	0	0	0	0	0	0/0	(12)
16	12	0	5	2	0	0	2/0	(13)

NOTES:

1. SN/S18W39 (V) 03/0924, C2
   SN/S19W42 03/1742, GRF (13.7)
   SF/S15W37 03/1723E, GRF (110)
2. SF/S08E35 10/1428
   SF/N11E49 10/1506
3. C2/~1100
   C1/~1540
   SF/S18W13 05/1837
4. SN/S18E42 15/0212
   SB/N10E61 (L) 15/0321
   SF/N14E66 15/1128
   GRF (136) 15/1357.2
   SN/N08E35 16/1814
   SF/N07E36 16/1845
   SF/N07E36 16/1914
   SF/N09E33 16/2038
5. SN/N08E09 (L) 28/0403, >C1
   SN/N06E13 28/1311, GRF (50), IV
6. SN/S05E72 27/2328E, C2
   SN/N03W01 (UH) 28/0100, GRF (35), C3, IV
   GRF (60) 28/0254, C0.6
7. GRF (40) 24/2000, C0.6–C1
   SN/S05W17 25/0755, C0.5
   GRF (50) 25/1450, C0.3
   SN/S07W22 (U) 25/1748
   SN/S09W27 26/0036, GRF (15), C2
8. SN/N08W17 22/0449
   SF/S06W62 22/0604
   SF/N17W08 22/0635
   SF/S01W58 22/0850
   SF/S07W78 23/1125
9. SF/S17E12 18/1851E, GRF (2100), ~C1
10. GRF (48.5) 24/1412.2
11. NO REPORTED EVENTS
12. NO REPORTED EVENTS
13. C1.8/0929
    C3.1/1233
    SN/N26W25 16/1822, GRF (150)
    GRF (0.7) 16/0837
    SN/N33E39 16/1447, GRF (68.2)

TABLE 5B. SOLAR ACTIVITY SUMMARY DATA DURING SELECTED CONTROL PERIODS (SUBGROUP B)

PRE–EVENT WINDOW NO.	YEAR	BEGIN	END	NO. FLARES IN WINDOW	NO. ANNOTATED FLARES	NO. GRF'S IN WINDOW	NO. X–RAY EVENTS IN WINDOW	NO. TYPE II's IN WINDOW	NO. TYPE IV's IN WINDOW	POSSIBLE NO. ASSOCIATIONS ≥2/≥3
4	1971	03–29 (0800)	03–30 (0800)	29	0	6	1	0	0	3/1
5	1972	01–07 (1500)	01–08 (1500)	7	1	1	0	0	0	0/0
6	1972	02–01 (0500)	02–02 (0500)	9	1	4	0	0	0	1/0
7	1973	01–10 (2300)	01–11 (2300)	13	2	4	4	2	2	4/2
8	1973	02–23 (1000)	02–24 (1000)	11	1	3	1	0	0	1/0
9	1973	03–23 (2100)	03–24 (2100)	24	1	4	4	0	0	4/3
10	1973	06–21 (0800)	06–22 (0800)	15	3	0	0	0	0	0/0
11	1973	07–17 (2200)	07–18 (2200)	12	0	0	0	1	0	1/0
12	1974	01–14 (0800)	01–15 (0800)	11	0	0	1	0	0	0/0
13	1975	03–22 (0000)	03–23 (0000)	1	0	0	0	0	0	0/0
14	1975	04–13 (0700)	04–14 (0700)	0	0	1	0	0	0	0/0
15	1976	11–26 (1800)	11–27 (1800)	0	0	0	0	0	0	0/0
16	1978	02–09 (1800)	02–10 (1800)	20	4	6	9	0	0	7/4

TABLE 6. MAGNETIC CLOUDS ASSOCIATED WITH CME'S SUMMARY DATA (SUBGROUP C)

(a) EVENT NO.	DATE OF CLOUD OCCURRENCE	(b) CLOUD PASSAGE BEGIN TIME	(c) CLOUD PASSAGE DURATION	(d) V_{MIN}	(d) V_{MAX}	(d) V_{AVG}	(e) TT	EVENT WINDOW BEGIN	EVENT WINDOW END	(f) WINDOW DURATION	(g) Hα	(g) RADIO
4	06-23-71	1400	50	321	349	335	124.4	06–18 (0500)	06–18 (1500)	10	0	84
5	02-17-72	0600	39	383	435	409	101.9	02–12 (1700)	02–13 (0600)	13	0	70
6	03-27-72	1700	25	380	432	406	102.6	03–23 (0300)	03–23 (1600)	13	0	159
7	04-17-72	2100	15	304	361	333	125.1	04–12 (0500)	04–13 (0200)	21	116	0
8	11-27-72	0000	48	395	482	430	94.9	11–22 (1600)	11–23 (1100)	19	0	0
9	09-26-73	0000	30	352	481	417	99.9	09–21 (0500)	09–22 (1200)	31	157	4
10	11-21-73	1500	14	355	398	377	110.5	11–16 (1800)	11–17 (0700)	13	0	0
11	05-25-75	1700	31	386	456	421	99.0	05–21 (0600)	05–21 (2300)	17	36	0
12	08-01-75	0300	21	353	411	382	109.1	07–27 (0600)	07–27 (2300)	17	0	0
13	11-17-75	0000	29	331	404	368	113.2	11–11 (2000)	11–12 (1800)	22	30	0
14	06-05-77	0300	21	336	384	360	115.7	05–30 (2300)	05–31 (1500)	16	0	0
15	09-26-77	2100	30	294	404	349	119.4	09–21 (0300)	09–22 (1400)	35	59	0
16	01-16-78	1200	48	303	335	319	130.6	01–10 (1800)	01–11 (0700)	13	29	0

[a] NUMBERING IS AS IN KB

[b] TIME IN UNIVERSAL TIME (UT)

[c] TIME IN HOURS

[d] VELOCITY IN $km\ s^{-1}$

[e] TRAVEL TIME (TT) IN HOURS

[f] WINDOW DURATION IN HOURS

[g] OBSERVING OUTAGES WITHIN THE WINDOW TOTAL THE NUMBER OF MINUTES LISTED

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 7A. SOLAR ACTIVITY SUMMARY DATA DURING CLOUD WINDOWS (SUBGROUP C)

EVENT NO.	NO. FLARES IN WINDOW	NO. ANNOTATED FLARES	NO. GRF's IN WINDOW	NO. X-RAY EVENTS IN WINDOW	NO. TYPE II's IN WINDOW	NO. TYPE IV's IN WINDOW	POSSIBLE NO. ASSOCIATIONS ≥2/≥3	NOTES
4	9	1	1	3	0	0	2/1	(1)
5	2	0	2	1	0	0	0/0	(2)
6	31	5	2	6	0	0	7/0	(3)
7	8	0	0	0	0	0	0/0	(4)
8	12	3	3	5	0	0	4/3	(5)
9	8	0	0	0	0	0	0/0	(6)
10	1	0	0	0	0	0	0/0	(7)
11	0	0	0	0	0	0	0/0	(8)
12	3	1	0	0	0	1	1/0	(9)
13	0	0	1	0	0	0	0/0	(10)
14	3	1	0	1	0	0	1/0	(11)
15	21	0	6	*	0	0	3/0	(12)
16	4	0	1	1	1	0	2/0	(13)

NOTES: * NO X-RAY DATA AVAILABLE

1. SF/S07W06 12/0600, GRF (55), C1
2. SF/N26E53 12/2043
   SF/S15E49 13/0309
   ?C1/~0505
   GRF (8) 12/1910
   GRF (30) 12/2145
3. SN/N06E15 (H) 23/0459, C1
   SN/N14W54 23/0940, GRF (161)
   SB/S17W36 23/1020, C2
   SN/N10E09 (H) 23/1233, C1
   SF/N09W18 (H) 23/1408, GRF (255)
   SF/N09W17 23/1501, C2
   SN/N10E08 (H) 23/1546, C3
4. SF/S07E01 12/0708
   SF/S12E24 12/1943
   SF/S14W15 12/2027
   SN/S10W51 13/0156
5. SN/S07W09 22/1633, GRF (45), C0.8
   SB/S07W10 (U) 22/1911, GRF (23), C5
   SB/S07W13 (U) 23/0200, M1
   SN/S15W54 23/0754, GRF (60), C1
6. 1F/N13E60 22/0535
   SN/N16W16 22/0920E
7. SF/N03E41 17/0000
   SF/N14E33 16/1607
8. NO REPORTED EVENTS
9. SF/N09W19 (H) 27/1815, IV
10. GRF (220U) 12/0801.6
11. SN/N22W36 (H) 31/1104, C1
12. SN/N11W87 21/1707E, GRF (7)
    ?F/N19W90 21/2235, GRF (33)
    1N/N11W90 22/0120, GRF (50)
13. 1N/N15W27 10/2202, II
    SF/N15W31 11/0256>9, C1

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 7B. SOLAR ACTIVITY SUMMARY DATA DURING SELECTED CONTROL PERIODS (SUBGROUP C)

PRE–EVENT WINDOW NO.	YEAR	BEGIN	END	NO. FLARES IN WINDOW	NO. ANNOTATED FLARES	NO. GRF'S IN WINDOW	NO. X–RAY EVENTS IN WINDOW	NO. TYPE II's IN WINDOW	NO. TYPE IV's IN WINDOW	POSSIBLE NO. ASSOCIATIONS ⩾2/⩾3
4	1971	06–14 (0500)	06–15 (0500)	14	0	0	0	0	0	0/0
5	1972	02–08 (1700)	02–09 (1700)	15	1	3	2	0	0	0/0
6	1972	03–19 (0300)	03–20 (0300)	14	2	5	0	0	0	3/0
7	1972	04–08 (0500)	04–09 (0500)	9	1	1	0	0	0	0/0
8	1972	11–18 (1600)	11–19 (1600)	8	0	0	0	0	0	0/0
9	1973	09–12 (0700)	09–13 (0700)	8	2	1	0	0	0	1/0
10	1973	11–12 (1800)	11–13 (1800)	3	2	0	0	0	0	0/0
11	1975	05–13 (1900)	05–14 (1900)	0	0	0	0	0	0	0/0
12	1975	07–23 (0600)	07–24 (0600)	17	3	1	0	0	0	0/0
13	1975	11–07 (2000)	11–08 (2000)	0	0	0	0	0	0	0/0
14	1977	05–26 (1800)	05–27 (1800)	3	0	0	0	0	0	0/0
15	1977	09–18 (1800)	09–19 (1800)	9	0	11	0	1	1	5/1
16	1977	12–31 (2100)	01–01 (2100)	12	1	8	8	0	0	6/2

ORIGINAL PAGE IS
OF POOR QUALITY

clouds preceding interaction regions (Table 5A) and associated with CME's (Table 7A). For those diagnostic phenomena occurring singly, the correlative events chosen and listed are flares and/or GRF and X-ray events listed in the SGD. (Type II radio events were always associated with flares and type IV events with flare/GRF events). There were three magnetic cloud events for which no candidate solar event appears; in these cases, no occurrences of diagnostic phenomena were reported in the SGD during the appropriate intervals. (One should note that the listing of GRF occurrences is based solely on the SGD record and that this record may be incomplete. For instance, though SGD reports hours of coverage for observatories which report type II and IV phenomena, the hours of coverage are not reported for observatories which normally report GRF events.)

Examination of the A and B portions of the odd-numbered tables shows that typically there are many proxy phenomena for each magnetic cloud, and almost equally many proxy phenomena during the pre-cloud windows, when no near-Earth clouds were reported at the appropriate later times. Logically, two explanations are allowed by this profusion of proxy phenomena in both cloud and pre-cloud windows: (1) if indeed the selected, proxy phenomena indicate the existence of coronal mass ejections, then there were mass ejections not only near the time of magnetic cloud emission from the Sun but also at times when no magnetic cloud was reported; or (2) perhaps the selected solar phenomena are poor proxies for the existence of coronal mass ejections.

An attempt was made to sort out these possibilities by examining clouds of subgroup (a), those following interplanetary shocks. If the interplanetary shocks initiated by dynamical processes in the solar wind are ignored, then it is expected that interplanetary shocks are typically the outwardly propagating remnants of solar coronal shocks. Meter-wave type II bursts are diagnostic of coronal shocks [6], and the shocks may be traced from the corona into the interplanetary medium by observing at lower and lower frequencies as the shocks propagate into regions of ever-decreasing density [41]. Meter-wave type II bursts are also diagnostic of the occurrence of coronal mass ejections [33]. Thus, it can be expected that meter-wave type II bursts are the proxy solar phenomenon which should serve as the linchpin in establishing a connection between the clouds of subgroup (a) and coronal mass ejections.

When looking at Tables 3A and 3B, it is found that type II radio bursts occurred in six of the nine cloud windows and occurred in three of the nine pre-cloud windows. Checking the central meridian distance of the flares and sub-flares (approximately equal numbers) from which these radio bursts presumably originated, it is found that the radio bursts in the six cloud windows all occurred within 49 deg of central meridian, while the radio bursts occurring during the pre-cloud windows were located farther than 63 deg from central meridian. Surprisingly, all six of the radio bursts associated with clouds occurred in the eastern hemisphere. To restate, of the nine magnetic clouds following interplanetary shocks, six had type II radio bursts within 49 deg of central meridian in the temporal window during which the magnetic cloud was emitted from the Sun. In contrast, not one of the nine pre-cloud windows had a meter-wave type II burst within 63 deg of central meridian passage.

These findings are entirely consistent with and support the idea that fast coronal mass ejections, expelled nearly radially from the Sun and accompanied by coronal shocks, propagated through the interplanetary medium to become the magnetic clouds detected at 1 AU and reported as subgroup (a) events.

The choice of the "right" proxy solar phenomenon or phenomena for the 26 magnetic clouds of subgroups (b) and (c) is not so obvious. The meter-wave type II bursts which were so dramatically correlated with the clouds following shocks are not expected to correlate well with the clouds of subgroups (b) and (c) which are without shocks. This expectation is proven by the data: type IIs occurred in only one of these 26 cloud windows and in only three of the corresponding 26 pre-cloud windows. None of these four radio bursts for the (b) and (c) subgroups can be associated with flares or sub-flares within

47 deg of central meridian; since all the radio burst events associated with subgroup (a) clouds occurred within 49 deg of central meridian, it is not surprising that clouds were not associated with these four radio bursts.

Motivated by the proven association between coronal mass ejections and gradual-rise-and-fall radio and LDE soft X-ray events [16, 26, 27] and the belief that long-duration X-ray events tend to be associated with long-duration H-alpha events [42, 43, 44], H-alpha duration and central meridian distance were examined for each of the flares occurring during each of the cloud and pre-cloud windows. For subgroup (a), long-duration H-alpha flares occurring during the cloud (pre-cloud) windows were clustered around (away from) central meridian. However, no such pattern emerged for subgroups (b) and (c). Combining the three cloud subgroups together, no indication was found that long-duration H-alpha flares were more prevalent near central meridian during cloud windows than during pre-cloud windows. Thus, even when coupled with longitude of occurrence, H-alpha duration of flares is not a good proxy phenomenon with which to correlate the existence of interplanetary magnetic clouds, and other proxy phenomena do not suggest themselves. Despite this situation, it is believed that the longitudinal distributions of the sites of cloud-associated and non-cloud-associated type II radio bursts will yield information on the size and directionality of emission of the clouds. In the non-association between solar events and observed magnetic clouds, and in the tendency for subgroup (b) and (c) clouds to be slower, it is believed there are further clues regarding the connection between coronal mass ejections and magnetic clouds. These matters will be pursued in a subsequent paper. Also, the association between magnetic clouds and X-ray LDEs is being investigated.

CONCLUSIONS

The most satisfying outcome of the present study would be to find that each magnetic cloud had a single candidate solar event which indicated that a single coronal mass ejection occurred on the Sun in the right place and at the right time to become the observed interplanetary magnetic cloud, and that no such candidate event occurred when no cloud was reported. In the near one-to-one association between meter-wave, solar, type II radio bursts and magnetic clouds following interplanetary shocks this satisfying outcome was found. For six of nine such magnetic clouds studied, there occurred a meter-wave type II radio burst within 49 deg of central meridian in the temporal window during which the cloud was emitted from the Sun. In the entire collection of 35 pre-cloud windows, during which no cloud was expected to be emitted, no meter-wave type II radio bursts were found closer to central meridian than E63 or W47. Thus, for clouds following shocks, meter-wave type II radio bursts occurring near central meridian accompanied the emission of magnetic clouds, whatever the cloud's near-Sun appearance. Because meter-wave type II radio bursts are well associated with coronal mass ejections [33], they are believed to be diagnostic of the emission of coronal mass ejections. Therefore, support is found for the hypothesis that magnetic clouds are 1-AU manifestations of coronal mass ejections in the case of magnetic clouds following shocks.

For magnetic clouds preceding interaction regions subgroup (b) and clouds associated with cold magnetic enhancements subgroup (c), it is less clear what proxy solar phenomena should be expected to link clouds with coronal mass ejections. For these clouds, a rather large number of proxy solar events were found around the times when the magnetic clouds were emitted toward Earth, but also nearly equal numbers during selected control periods when clouds presumably were not emitted earthward. Thus, these proxy events are of little value for diagnosing or predicting the existence of magnetic clouds. The profusion of solar phenomena which are believed to give proxy indications of the existence of coronal mass ejections is consistent with, but does not compel one to believe, the hypothesis that magnetic clouds are 1 AU manifestations of coronal mass ejections.

In summary, it has been shown that for the generally faster clouds following interplanetary shocks, meter-wave type II radio bursts give good evidence that coronal mass ejections occurred in the right places and times to become the magnetic clouds detected at 1 AU. Also noted was the one reported case of a fast coronal mass ejection which was observed by Burlaga et al. [5] to leave the limb of the Sun and at the appropriate later time (about 42 hr to travel 0.5 AU) to pass over the Helios spacecraft as a magnetic cloud following a shock. Klein and Burlaga argue quite reasonably that all magnetic clouds are manifestations of the same phenomenon. Therefore, despite the lack of compelling evidence for the clouds of subgroups (b) and (c), it is believed that coronal mass ejections, even slow ones, do become interplanetary magnetic clouds.

REFERENCES

1. Burlaga, L., Sittler, E., Mariani, F., and Schwenn, R.: J. Geophys. Res., Vol. 86, 1981, p. 6673.

2. Klein, L. W. and Burlaga, L. F.: J. Geophys. Res., Vol. 87, 1982, p. 613.

3. Burlaga, L. F. and Behannon, K. W.: Solar Phys., Vol. 81, 1982, p. 181.

4. Burlaga, L. F., Klein, L., Sheeley, Jr., N., Howard, R. A., Koomen, M. J., Schwenn, R., and Rosenbauer, H.: EOS, Vol. 63, 1982, p. 425.

5. Burlaga, L. F., Klein, L., Sheeley, Jr., N., Howard, R. A., Koomen, M. J., Schwenn, R., and Rosenbauer, H.: Geophys. Res. Letters, Vol. 9, 1982, p. 1317.

6. Hundhausen, A. J.: Coronal Expansion and Solar Wind. Springer-Verlag, New York, New York, 1972.

7. King, J. H.: Interplanetary Magnetic Field Data Book. National Science Data Center, NASA/GSFC, Greenbelt, MD, April 1975.

8. King, J. H.: Interplanetary Medium Data Book – Appendix. NSSDC/WDC-A-R&S 77-04a, National Space Science Data Center, NASA/GSFC, Greenbelt, MD, September 1977.

9. King, J. H.: Interplanetary Medium Data Book Supplement 1 1975-1978. NSSDC/WDC-A-R&S 79-08, National Space Science Data Center, NASA/GSFC, Greenbelt, MD, December 1979.

10. Rust, D. M., Hildner, E., Dryer, M., Hansen, R. T., McClymont, A. N., McKenna Lawlor, S. M. P., Schmahl, E. J., Steinolfson, R. S., Tandberg-Hanssen, E., Tousey, R., Webb, D. R., and Wu, S. T.: Mass Ejections. Chapter 7, Solar Flares: A Monograph from Skylab Solar Workshop II (ed., P. A. Sturrock), Colorado Associated University Press, Boulder, CO, 1980, p. 273.

11. Poland, A. I., Howard, R. A., Koomen, M. J., Michels, D. J., and Sheeley, Jr., N. R.: Solar Phys., Vol. 69, 1981, p. 169.

12. Warwick, J. W.: Sweep-Frequency Measurements of Solar Bursts. Chapter 8, Solar System Radio Astronomy (ed., J. Aarons), Plenum Press, New York, New York, 1965, p. 131.

13. Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: J. Geophys. Res., Vol. 79, 1974, p. 4581.

14. Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: Solar Phys., Vol. 40, 1975, p. 439.

15. Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: Solar Phys., Vol. 48, 1976, p. 389.

16. Sheeley, Jr., N. R., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Tousey, R., Smith, Jr., J. B., Speich, D. M., Tandberg-Hanssen, E., Wilson, R. M., deLoach, A. C., Hoover, R. B., and McGuire, J. P.: Solar Phys., Vol. 45, 1975, p. 366.

17. Sheeley, Jr., N. R., Howard, R. A., Koomen, M. J., Michels, D. J., and Poland, A. I.: Astrophys. J. (Letters), Vol. 238, 1980, p. L161.

18. Dodge, J. C.: Solar Phys., Vol. 42, 1975, p. 445.

19. Dulk, G. A., Smerd, S. F., MacQueen, R. M., Gosling, J. T., Magun, A., Stewart, R. T., Sheridan, K. V., Robinson, R. D., and Jacques, S.: Solar Phys., Vol. 49, 1976, p. 369.

20. Hildner, E., Gosling, J. T., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: Solar Phys., Vol. 42, 1975, p. 163.

21. Hildner, E., Gosling, J. T., and Hansen, R. T.: Solar Phys., Vol. 45, 1975, p. 363.

22. Hildner, E., Gosling, J. T., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: Solar Phys., Vol. 48, 1976, p. 127.

23. Koutchmy, S.: Solar Corona. Chapter 6, Illustrated Glossary for Solar and Solar-Terrestrial Physics (eds., A. Bruzek and C. J. Durrant), Astrophysics and Space Science Library, Vol. 69, D. Reidel Publ. Co., Dordrecht, Holland, 1977, p. 39.

24. Tandberg-Hanssen, E.: Prominences. Chapter 10, Illustrated Glossary for Solar and Solar-Terrestrial Physics (eds., A. Bruzek and C. J. Durrant), Astrophysics and Space Science Library, Vol. 69, D. Reidel Publ. Co., Dordrecht, Holland, 1977, p. 97.

25. Fokker, A. D.: Solar Radio Emission. Chapter 11, Illustrated Glossary for Solar and Solar-Terrestrial Physics (eds., A. Bruzek and C. J. Durrant), Astrophysics and Space Science Library, Vol. 69, D. Reidel Publ. Co., Dordrecht, Holland, 1977, p. 111.

26. Kahler, S.: Astrophys. J., Vol. 214, 1977, p. 891.

27. Smith, Jr., J. B., Speich, D. M., Wilson, R. M., and Reichmann, E. J.: Long Duration Soft X-Ray Transients: Physical Parameters and Morphology. Contributed Papers to the Study of Travelling Interplanetary Phenomena/1977 (Proceedings of COSPAR Symp. B, Tel Aviv, Israel, June 1977) (eds., M. A. Shea, D. F. Smart, and S. T. Wu), AFGL-TR-77-0309, Special Reports No. 209, Air Force Geophysical Laboratory, Hanscom AFB, MA, 29 December 1977, p. 3.

28. Smith, Jr., J. B., Speich, D. M., Wilson, R. M., Tandberg-Hanssen, E., and Wu, S. T.: Solar Phys., Vol. 52, 1977, p. 379.

29. Wilson, R. M., Reichmann, E. J., Smith, Jr., J. B., and Speich, D. M.: BAAS, Vol. 9, 1977, p. 315.

30. Kahler, S. W., Hildner, E., and van Hollebeke, M. A. I.: Solar Phys., Vol. 57, 1978, p. 429.

31. Dryer, M., Wu, S. T., Steinolfson, R. S., Tandberg-Hanssen, E., and Wilson, R. M.: Magnetohydrodynamic Simulation of Coronal Mass Ejections with the Solar Wind. A Close-Up of the Sun (eds., M. Neugebauer and R. W. Davies), JPL Publication 78-70, California Institute of Technology, Pasadena, CA, 1 September 1978, p. 367.

32. Dryer, M., Wu, S. T., Steinolfson, R. S., and Wilson, R. M.: Astrophys. J., Vol. 227, 1979, p. 1059.

33. Munro, R. H., Gosling, J. T., Hildner, E., MacQueen, R. M., Poland, A. I., and Ross, C. L.: Solar Phys., Vol. 61, 1979, p. 201.

34. Gergely, T. E., Kundu, M. R., Munro, R. H., and Poland, A. I.: Astrophys. J., Vol. 230, 1979, p. 575.

35. Fisher, R., Garcia, C. J., and Seagraves, P.: Astrophys. J. (Letters), Vol. 246, 1981, p. L161.

36. Fisher, R. R., and Poland, A. I.: Astrophys. J., Vol. 246, 1981, p. 1004.

37. Svestka, Z.: Flare Observations. Chapter 2, Solar Flare Magnetohydrodynamics (ed., E. R. Priest), The Fluid Mechanics of Astrophysics and Geophysics, Vol. 1, Gordon and Breach Science Publ., New York, New York, 1981, p. 47.

38. Joselyn, J. A. and McIntosh, P. S.: J. Geophys. Res., Vol. 86, 1981, p. 4555.

39. Howard, R. A., Michels, D. J., Sheeley, Jr., N. R., and Koomen, M. J.: Astrophys. J. (Letters), Vol. 263, 1982, p. L101.

40. Cliver, E. W., Kahler, S. W., and McIntosh, P.: Astrophys. J., Vol. 264, 1983, p. 699.

41. McLean, D. J.: Shock Waves and the Ejection of Matter from the Sun: Radio Evidence. Coronal Disturbances, IAU Symp. No. 57 (ed., G. Newkirk, Jr.), D. Reidel Publ. Co., Dordrecht, Holland, 1974, p. 301.

42. Drake, J. F.: Solar Phys., Vol. 16, 1971, p. 152.

43. Krieger, A., Paolini, F., Vaiana, G. S., and Webb, D.: Solar Phys., Vol. 22, 1972, p. 150.

44. Wilson, R. M.: NASA TM (in preparation).

APPROVAL

EVIDENCE LINKING CORONAL MASS EJECTIONS WITH INTERPLANETARY "MAGNETIC CLOUDS"

By Robert M. Wilson and Ernest Hildner

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

A. J. DESSLER
Director, Space Science Laboratory

☆ U.S. GOVERNMENT PRINTING OFFICE 1984—746-070/125